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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

COOLING METHOD AND MANUFACTURING METHOD OF METAL PART AND COOLING APPARATUS FOR METAL PART

Technical Field

[0001] The present invention relates to a method of cooling a metal part by immersing the metal part in a cooling liquid, a manufacturing method of a metal part by using this cooling method, and a cooling apparatus for a metal part.

Background Art

[0002] Quenching treatment and solid solution treatment are heat treatments which involve immersing a metal part heated to a high temperature into cooling liquids consisting of a mineral oil (a quenching oil), water or an aqueous solution of water-soluble coolant and the like, to rapidly cool the metal part. Although these cooling liquids are excellent in the stability of cooling and cost efficiency, the following point can be mentioned as a problem. That is, the instant a metal part heated to a high temperature is immersed in these cooling liquids, these cooling liquids vaporize at an interface with the metal part, generating a film of vapor (hereinafter called a "vapor film") on the surface of the metal part. Because this vapor film retards the cooling of the metal part, in particular, when the vapor film becomes partially stable due to the shape of the metal part, the arrangement of the metal part in a cooling tank, and the like, the metal part is not uniformly cooled and deformation and soft spots (hardness difference) occur in the metal part.

[0003] To solve this problem, a conventional practice has been to stir a cooling liquid with a metal part immersed by means of convection as strongly as possible, so that positive heat exchange occurs at the interface between the vapor film and the cooling liquid and the temperature of the surface of the metal part is lowered, thereby rapidly breaking a vapor film.

[0004] In JP2003-286517A (hereinafter referred to as Patent Document 1), there is proposed a method by which a cooling liquid in which a metal part is immersed is stirred by oscillations and jet flows, and horizontal and vertical flows are generated in the cooling liquid, whereby a vapor film is broken and bubbles generated from the broken vapor film are caused to diffuse in the cooling liquid and disappear.

[0005] However, in the method described in Patent Document 1 above, the cooling liquid is stirred when the vapor film is broken and, therefore, strong flows are generated in the cooling liquid and uniform breakage of the vapor film is apt to be hindered. Therefore, this method described in Patent Document 1 has room for further improvement in that a metal part is uniformly cooled.

[0006] Hence, the present invention has been made in view of the above circumstances and has as its object the provision of a method of uniformly cooling a metal part by uniformly breaking a vapor film which is generated by the vaporization of a cooling liquid on a surface of the metal part.

Disclosure of the Invention

[0007] To solve this problem, the present inventors earnestly devoted themselves to investigations and as a result they found out that a vapor film formed by the vaporization of a cooling liquid on the surface of a metal part is kept in a stable manner by the pressure in the interior of the film, and that the vapor film can be effectively broken by shattering the stability of this vapor film.

[0008] That is, the present invention provides a cooling method of cooling a metal part by immersing the heated metal part in a cooling liquid, which is characterized in that by applying a repeatedly varying pressure to a vapor film which is formed when the cooling liquid vaporizes on a surface of the metal part, the vapor film is broken without stirring the cooling liquid.

[0009] According to this cooling method, when a repeatedly varying pressure is applied to a vapor film, the vapor film repeats expansion and contraction and fluctuates, and the vapor film is broken, with a portion where the film thickness has decreased due to this fluctuation

serving as an initiation point. At this time, by applying a repeatedly varying pressure to the vapor film without stirring the cooling liquid, weak flows like natural convection are generated in the cooling liquid, but strong flows are not generated as would be the case when the cooling liquid is stirred. For this reason, the vapor film can be uniformly broken.

[0010] In the cooling method of the present invention, examples of a method of applying a repeatedly varying pressure to the vapor film include a method of applying oscillations to the cooling method, a method of changing the liquid-level pressure of the cooling liquid, and a method of performing the application of a repeatedly varying pressure by combining these two methods. As a method of applying a repeatedly varying pressure to the vapor film, it is possible to mention also a method by which the metal part is caused to swing. Furthermore, the pressure applied to the vapor film may be continuously varied or it may be intermittently varied like pulse oscillation.

[0011] In the cooling method of the present invention, a method of applying oscillations to the cooling liquid is not especially limited so long as it does not generate strong flows in the cooling liquid, and examples of methods of applying oscillations to the cooling liquid include, for example, a method which involves providing an oscillator, such as an oscillating plate and a rotating body, in a cooling tank, and causing the oscillating plate to perform reciprocating motions or causing the rotating body to perform rotational motions. Examples of a method of applying oscillations to the cooling liquid also include a method which involves providing multiple oscillators in the cooling tank and causing these oscillators to oscillate. According to this method, it is possible to apply oscillations due to the resonance by the multiple oscillators to the cooling liquid and to apply oscillations which are partially different within the cooling tank.

[0012] Also in the cooling method of the present invention, when the method which involves applying oscillations to the cooling liquid is adopted as a method of applying a repeatedly varying pressure to the vapor film, at least either of the amplitude and frequency of the vibrations may be adjusted according to the thickness of the vapor film.

[0013] The thickness of the vapor film changes depending on the size, temperature and shape of the metal part, the kind and temperature of the cooling liquid, the pressure applied to

the liquid and the like. For example, when the vapor film is thick, it is preferred to make the amplitude larger, and when the vapor film is thin, it is preferred to make the frequency higher.

[0014] Furthermore, in the cooling method of the present invention, when the method which involves applying oscillations to the cooling liquid is adopted as a method of applying a repeatedly varying pressure to the vapor film, at least either of the amplitude and frequency of the oscillations may be adjusted according to the condition of the cooling liquid.

[0015] The condition of the cooling liquid changes in the order: (1) a vapor film stage at which a vapor film is present on the surface of a metal part, (2) a boiling stage at which this vapor film is broken and removed from the surface of the metal part, with the result that the metal part is exposed and the cooling liquid which comes into contact with this exposed surface boils, and (3) a convection stage at which boiling comes to an end and convection starts. For example, it is preferred to make the amplitude larger in the former period of the vapor film stage at which a vapor film exists in a stable manner and to make the frequency higher from the latter period of the vapor film stage at which the vapor film begins to be broken to before the transition to the boiling stage.

[0016] In the cooling method of the present invention, the breakage effect of the vapor film cannot be expected if the amplitude of oscillations applied to the cooling liquid is too small; on the other hand, if the amplitude is too large, the liquid surface of the cooling liquid becomes wavy and in some cases strong flows are generated. From this point of view, it is preferred that when oscillations are applied by use of an oscillating plate, the amplitude expressed by the swing width of the oscillating plate be not less than 2 mm. When oscillations are applied by a pressure, it is preferred that the amplitude expressed by an amount of change in the pressure be not less than 1% (for example, not less than 100 Pa) of the pressure which is applied to the cooling liquid in the state that the oscillations are not being applied.

[0017] If the frequency applied to the cooling liquid is too low, a change in the pressure is gentle and the vapor film does not fluctuate, with the result that the breakage effect of the vapor film cannot be expected. On the other hand, if the frequency applied to the cooling

liquid is too high, the fluctuation of the vapor film becomes too fine, with the result that the breakage effect of the vapor film cannot be expected. From this point of view, when an oscillating apparatus provided with a vibration motor made by URAS TECHNO (trade name: URAS TECHNO VIBRATOR) is used, the frequency of oscillations applied to the cooling liquid is preferably 5 to 80 Hz, more preferably 20 to 30 Hz.

[0018] Furthermore, when oscillations applied to the cooling liquid have a low frequency and a large amplitude, it is necessary to prevent the liquid surface of the cooling liquid from becoming wavy and, therefore, the construction of the cooling tank becomes complex. When oscillations having a small amplitude and a high frequency as ultrasonic waves are applied to the cooling liquid, the fluctuation of the vapor film becomes too fine and, therefore, the breakage effect of the vapor film cannot be expected.

[0019] In the cooling method of the present invention, it is preferred that the cooling liquid be stirred after the vapor film begins to be broken so that bubbles formed by the breakage of the vapor film is caused to diffuse in the cooling liquid.

[0020] As a result of this, it is possible to cause the bubbles formed from the broken vapor film to diffuse uniformly and rapidly in the cooling liquid and disappear, with the result that the cooling for a metal part may be performed uniformly and rapidly. This stirring of the cooling liquid is effective particularly when the rapid diffusion of bubbles is required, for example, in a case where metal parts are cooled in a massive amount at a time, in a case where metal parts having a large volume are cooled, and the like.

[0021] Examples of a method of stirring the cooling liquid include jet stirring and it is preferable to adopt a method by which a uniform flow is formed in the cooling liquid from below upward. It is preferred that the timing for starting the stirring of the cooling liquid is synchronized with the point of time at which the vapor film begins to be broken.

[0022] The stirring may be performed either after stopping the application of a varying pressure to the vapor film or while continuously applying a varying pressure. As for which method is adopted, any one of the methods is selected according to the size, kind, or quantity of a metal part to be cooled.

[0023] For example, when a metal part which is apt to be deformed is cooled, in order to make gentle the cooling at the convection stage of the cooling liquid, it is preferable to perform the stirring after the application of a varying pressure to the vapor film is stopped. That is, it is preferable not to apply oscillations during the stirring of the cooling liquid. On the other hand, in a case where metal parts are cooled in a massive amount at a time and in a case where metal parts having a large volume are cooled, in order to perform strong cooling even at the convection stage of the cooling liquid, it is preferable to perform the stirring, with a varying pressure applied to the vapor film. That is, it is preferable to apply oscillations simultaneously with the stirring of the cooling liquid.

[0024] Furthermore, in the cooling method of the present invention, it is preferable to adjust at least either of the intensity of the stirring and the direction of a flow generated by the stirring according to the condition of the cooling liquid and the condition of the metal part in the cooling liquid.

[0025] At the boiling stage of the cooling liquid, it is preferable to cause the bubbles formed from the broken vapor film to diffuse uniformly and rapidly in the cooling liquid and disappear. For this reason, it is preferable to perform strong stirring from the later period of the vapor film stage at which the vapor film begins to be broken to before the transition to the convection stage. Also, in a case where the longitudinal direction of a metal part is arranged toward a vertical direction in the cooling liquid, it is preferable to ensure that the direction of flows generated by stirring is a vertical direction and in a case where the longitudinal direction of a metal part is arranged toward a horizontal direction in the cooling liquid, it is preferable to ensure that the direction of flows generated by stirring is a horizontal direction.

[0026] Incidentally, the cooling method of the present invention can be favorably used in the quenching treatment and solid solution treatment of metal parts.

[0027] The present invention also provides a method of manufacturing a metal part, which is characterized in that the manufacturing method comprises a step of heating a metal part and a step of cooing the metal part after the heating thereof by immersing the metal part in a cooling liquid, and in that in the cooling step, by applying a repeatedly varying pressure to a

vapor film which is formed when the cooling liquid vaporizes on a surface of the metal part, the vapor film is broken without stirring the cooling liquid.

[0028] According to this manufacturing method, the uniformity of the cooling of a metal part is improved and the deformation or the soft spots thereof become less apt to occur. Therefore, it is possible to obtain a high-accuracy and high-quality metal part.

[0029] Incidentally, in the manufacturing method of the present invention, in the same way as with the above-described cooling method, examples of a method of applying a repeatedly varying pressure to the vapor film includes a method of applying oscillations to the cooling method, a method of changing the liquid-level pressure of the cooling liquid, a method of performing the application of a repeatedly varying pressure by combining these two methods, and a method of fluctuating a metal part.

[0030] Also, as a method of applying oscillations to the cooling liquid, in the same way as with the above-described cooling method, it is possible to mention a method by which one or multiple oscillators are caused to oscillate.

[0031] Furthermore, in the manufacturing method of the present invention, when the method of applying oscillations to the cooling liquid is adopted as a method of applying a repeatedly varying pressure to the vapor film, in the same way as with the above-described cooling method, at least either of the amplitude and frequency of the oscillations may be adjusted according to the thickness of the vapor film and the condition of the cooling liquid.

[0032] Moreover, in the manufacturing method of the present invention, it is preferred that the cooling method includes stirring the cooling liquid after the vapor film begins to be broken so that bubbles formed by the breakage of the vapor film is caused to diffuse in the cooling liquid. At this time, in the same way as with the above-described cooling method, it is preferable to adjust at least either of the intensity of the stirring and the direction of a flow generated by the stirring according to the condition of the cooling liquid and the condition of the metal part in the cooling liquid.

[0033] Furthermore, the present invention provides a cooling apparatus for a metal part, which is characterized in that the cooling apparatus comprises means for cooling a metal part after the heating thereof by immersing the metal part in a cooling liquid, and in that the

cooling means applies a repeatedly varying pressure to a vapor film which is formed when the cooling liquid vaporizes on a surface of the metal part, and breaks the vapor film without stirring the cooling liquid.

[0034] According to this cooling apparatus, the uniformity of the cooling of a metal part is improved and the deformation or the soft spots thereof become less apt to occur. Therefore, it is possible to obtain a high-accuracy and high-quality metal part.

[0035] Incidentally, in the cooling apparatus of the present invention, in the same way as with the above-described cooling method, examples of a method of applying a repeatedly varying pressure to the vapor film includes a method of applying oscillations to the cooling method, a method of changing the liquid-level pressure of the cooling liquid, a method of performing the application of a repeatedly varying pressure by combining these two methods, and a method of fluctuating a metal part. Furthermore, the pressure applied to the vapor film may be continuously varied or it may be intermittently varied like pulse oscillation.

[0036] Also, in the cooling apparatus of the present invention, as a method of applying oscillations to the cooling liquid, in the same way as described above, it is possible to mention a method by which one or multiple oscillators are caused to oscillate.

[0037] Furthermore, in the cooling apparatus of the present invention, when the method of applying oscillations to the cooling liquid is adopted as a method of applying a repeatedly varying pressure to the vapor film, in the same way as described above, at least either of the amplitude and frequency of the oscillations may be adjusted according to the thickness of the vapor film and the condition of the cooling liquid.

[0038] Furthermore, in the cooling apparatus of the present invention, it is preferred that the above-described cooling means stir the cooling liquid after the vapor film begins to be broken so that the bubbles formed by the breakage of the vapor film are caused to diffuse in the cooling liquid. At this time, it is preferable to adjust at least either of the intensity of the stirring and the direction of a flow generated by the stirring according to the condition of the cooling liquid and the condition of the metal part in the cooling liquid.

Brief Description of the Drawings

[0039] Figure 1 is a schematic configuration diagram showing an example of a cooling apparatus used in a cooling method of a metal part related to the present invention;

[0040] Figure 2 is a diagram showing pressure changes occurring in the cooling liquid when an oscillation device is actuated in the cooling apparatus of this embodiment;

[0041] Figure 3 is a diagram showing pressure changes occurring in the cooling liquid when a stirrer is actuated in the cooling apparatus of this embodiment;

[0042] Figure 4 is a schematic configuration diagram showing another example of a cooling apparatus used in a cooling method of a metal part related to the present invention;

[0043] Figure 5 is a diagram showing cooling curves on the side surfaces of round bar test pieces made of stainless steel subjected to cooling treatments No. 1 to No. 4; and

[0044] Figure 6 is a diagram showing cooling curves on the side surfaces of round bar test pieces made of stainless steel subjected to cooling treatments No. 5 and No. 6.

Best Mode for Carrying Out the Invention

[0045] An embodiment of the present invention will be described below with reference to the drawings.

[0046] In this embodiment, a description will be given of a case where metal parts are manufactured by using a cooling apparatus for a metal part related to the present invention.

[0047] Figure 1 is a schematic configuration diagram showing an example of a cooling apparatus used in a cooling method of a metal part related to the present invention.

[0048] As shown in Figure 1, this cooling apparatus is equipped with a cooling tank 2 which contains a cooling liquid 1, a container 3 which houses metal parts, two oscillation devices 10, a stirrer 20, and a controller 30. In the upper part of this cooling apparatus, there is arranged a heating device 40 which heats the metal parts. And the container 3 which houses metal parts heated by this heating device 40 is immersed in the middle part of the cooling tank 2 by use of an elevator apparatus not shown in the figure.

[0049] The oscillation device 10 is equipped with one oscillating plate 11 and a drive unit 12 which oscillates this oscillating plate 11 with a prescribed amplitude and a prescribed frequency. This oscillating plate 11 is disposed near the side surface of the container 3 in

the cooling tank 2 perpendicularly, with the plate surface thereof facing the container 3. When this oscillation device 10 is actuated, the oscillating plate 11 performs horizontal reciprocal motions and oscillations 4 are generated. The oscillations 4 are applied to the cooling liquid 1. By adjusting each of the frequencies and amplitudes of the two oscillation devices 10, it is possible to apply oscillations generated by the resonance of the two oscillating plates 11 or oscillations which differ on both sides of the container 3.

[0050] The stirrer 20 is equipped with a propeller 21 which is disposed, with a shaft thereof facing a vertical direction, multiple flow regulating plates 22, and a drive unit 23 which controls the rotational motions of the propeller 21, all these three members being present sideways from the oscillating plate 11 in the cooling tank 2. By actuating this stirrer 20, the propeller 21 performs rotations and the cooling liquid 1 is stirred, with the result that in the cooling liquid 1, upward flows are generated which move along the flow regulating plate 22 from below the container 3 upward.

[0051] The controller 30 is disposed outside the cooling tank 2, and constructed so as to control the timing for actuating the drive unit 12 of the oscillation device 10 and the drive unit 23 of the stirrer 20. Also, the controller 30 is constructed so as to control the drive unit 12 of the oscillation device 10 according to the thickness of the vapor film or the condition of the cooling liquid 1 and, at the same time, so as to control the drive unit 23 of the stirrer 20 according to the condition of the cooling liquid 1 or the condition of metal parts in the cooling liquid 1.

[0052] A strain-gauge pressure sensor was installed in the cooling tank 2 of this cooling apparatus and pressure changes occurring in the cooling liquid 1 within the cooling tank 2 were measured in a case where the oscillation device 10 and the stirrer 20 are individually actuated.

[0053] Figure 2 is a graph showing pressure changes occurring in the cooling liquid when the oscillating plate of the oscillation device is actuated under such a condition that the frequency is 40 Hz. Figure 3 is a graph showing pressure changes occurring in the cooling liquid when the stirrer is actuated under such a condition that upward flows generated in the cooing liquid amount to a flow rate of 30 m^3/h. In this graph, the fluctuation width of the

electromotive force of the sensor on the ordinate indicates the magnitude of the amount of change in the pressure (a relative value) and a numerical value of the electromotive force of the sensor indicates the intensity of a flow generated in the cooling liquid (a relative value).

[0054] As shown in Figures 2 and 3, when the oscillation device 10 was actuated, such pressure changes that the electromotive force of the sensor became 0.02 V or so occurred repeatedly in the cooling liquid, whereas pressure changes scarcely occurred in the cooling liquid when the stirrer 20 was actuated.

[0055] Flows generated in the cooling liquid 1 by the oscillation device 10 were weak compared to those occurred at the actuation of the stirrer 20. From this fact it could be ascertained that when the oscillation device 10 is actuated, a repeatedly varying pressure is applied to the cooling liquid 1 without the generation of strong flows, whereas by the actuation of the stirrer 20, a varying pressure is not applied although strong flows are formed in the cooling liquid 1.

[0056] Figure 4 is a schematic configuration diagram showing another example of a cooling apparatus used in a cooling method of a metal part related to the present invention.

[0057] As shown in Figure 4, this cooling apparatus is equipped with a cooling tank 2 containing a cooling liquid 1, a container 3 which houses metal parts to be subjected to cooling treatment, a gas introduction pipe 5 which introduces a gas into the cooling tank 2, a gas exhaust pipe 6 which exhausts the gas from the cooling tank 2, a stirrer 20 in which a propeller 21 is disposed sideways in the cooling tank 2, with a shaft thereof facing a vertical direction, and a controller 50 disposed outside the cooling tank 2. And in the same way as with the cooling apparatus shown in Figure 1 described above, the container 3 which houses metal parts heated by a heating device 40 is immersed in the middle part of the cooling tank 2. Incidentally, the same numerals refer to the same parts as those of the cooling apparatus shown in Figure 1 described above, and description of these parts are omitted.

[0058] The gas introduction pipe 5 can introduce a gas into the cooling tank 2 by use of a solenoid valve 5a connected to the controller 50.

[0059] The gas exhaust pipe 6 can discharge the gas in the cooling tank 2 by use of a solenoid valve 6a connected to the controller 50.

[0060] The controller 50 is constructed so as to continue introducing a gas into the cooling tank 2 by opening the solenoid valve 5a of the gas introduction pipe 5 and repeatedly perform the opening and closing the solenoid valve 6a of the gas exhaust pipe 6. As a result of this, it is possible to change the pressure on the liquid level of the cooling liquid 1 which has entered the cooling tank 2. Also, the controller 50 is constructed so as to start the actuation of the stirrer 20 at the point of time when the vapor film begins to be broken.

[0061] Furthermore, the controller 50 is constructed so as to control the gas volume introduced from the gas introduction pipe 5 and the timing for the opening and closing of the solenoid valve 6a of the gas exhaust pipe 6 according to the condition of the vapor film and the cooling liquid 1 and so as to control a drive unit 23 of the stirrer 20 according to the condition of the cooling liquid 1 and metal parts in the cooling liquid 1.

[0062] By use of the cooling apparatus of the above-described construction, the cooling of metal parts was performed by a method corresponding to the embodiment of the present invention and by a method corresponding to a conventional method.

[0063] Round bar test pieces made of stainless steel (metal parts) having a diameter of 12 mm, which had been heated to 830°C, were immersed in a quenching oil (a cooling liquid) 1 at 70°C and cooled by the methods of No. 1 to No. 5 shown below. Incidentally, in Nos. 1 to 3 and Nos. 5 and 6, cooling was performed by use of the cooling apparatus shown in Figure 1 described above (hereinafter called "the first cooling apparatus"), and in No. 4, cooling was performed by use of the cooling apparatus shown in Figure 4 shown above. Incidentally, the amplitude of oscillations 4 applied to the quenching oil 1 in the first cooling apparatus is expressed by the swing width of the oscillating plate 11. Incidentally, each cooling method is automatically performed by the execution of the arithmetic processing stored beforehand in the controllers 30, 50.

[0064] In No. 1, first, the oscillation device 10 was actuated, whereby the oscillating plate 11 was caused to oscillate with a frequency of 40 Hz and an amplitude of 4 mm, and the oscillations were applied to the quenching oil 1 for 2 seconds. Next, the oscillation device 10 was stopped and simultaneously the stirrer 20 was actuated, whereby the quenching oil 1 was jet-stirred by upward flows at a flow rate of 30 m^3/h.

[0065] In No. 2, the oscillation device 10 was actuated, whereby the oscillating plate 11 was caused to oscillate with a frequency of 40 Hz and an amplitude of 4 mm, and the oscillations were applied to the quenching oil 1.

[0066] In No. 3, the oscillation device 10 was actuated, whereby the oscillating plate 11 was caused to oscillate with a frequency of 40 Hz and an amplitude of 4 mm, and simultaneously the stirrer 20 was actuated, whereby the quenching oil 1 was jet-stirred by upward flows at a flow rate of 30 m^3/h.

[0067] In No. 4, the solenoid valve 5a was opened and the nitrogen gas from the gas introduction pipe 5 was continued to be introduced into the cooling tank 2. With the liquid-level pressure of the quenching oil 1 kept at 0.12 MPa, the opening and closing of the solenoid valve 6a of the gas exhaust pipe 6 was performed twice per second for a duration of 15 seconds, whereby the pressure applied to the liquid level was repeatedly varied.

[0068] In No. 5, the quenching oil 1 was allowed to undergo natural convection.

[0069] In No. 6, the stirrer 20 was actuated, whereby the quenching oil 1 was jet-stirred by upward flows at a flow rate of 30 m^3/h.

[0070] And in the cooling process of Nos. 1 to 6, the temperature on the side surface of a round bar test piece made of stainless steel was measured and a cooling curve of each test piece was prepared. The results are shown in Figures 5 and 6.

[0071] Figure 5 shows cooling curves on the side surfaces of round bar test pieces made of stainless steel cooled under the conditions of No. 1 to No. 4. Figure 6 shows cooling curves on the side surfaces of round bar test pieces made of stainless steel cooled under the conditions of No. 5 and No. 6.

[0072] As shown in Figure 5, in the No. 1 method which involves performing cooling by jet stirring of the quenching oil 1 after the application of oscillations to the quenching oil 1, in 1.9 seconds after the immersion of a test piece in the quenching oil 1, a change occurred from gentle cooling to abrupt cooling. This point of change is called a "characteristic point."

[0073] In both the No. 2 method which involves performing cooling by applying oscillations to the quenching oil 1 and the No. 3 method which involves performing cooling by jet stirring the quenching oil 1 simultaneously with the application of oscillations to the

quenching oil 1, a characteristic point was observed in 2.7 seconds after the immersion of test pieces in the quenching oil 1.

[0074] In the No. 4 method which involves performing cooling by repeatedly varying the liquid-level pressure of the quenching oil 1, a characteristic point was observed in 2.7 seconds after the immersion of a test piece in the quenching oil 1.

[0075] It might be thought that because in No. 2, the quenching oil 1 is not jet-stirred after the application of oscillations to the quenching oil 1, it takes time for the bubbles formed by the breakage of a vapor film to diffuse, with the result that the point of time at which a characteristic point is observed lags behind that of No. 1.

[0076] Also, it might be thought that because in No. 3, cooling is performed by jet-stirring the quenching oil 1 simultaneously with the application of oscillations to the quenching oil 1, strong flows are generated in the cooling liquid and uniform breakage of a vapor film is impeded, with the result that the point of time at which a characteristic point is observed lags behind that of No. 1.

[0077] Furthermore, it might be thought that because in No. 4, the quenching oil 1 is not jet-stirred after the varying of the liquid-level pressure of the quenching oil 1, it takes time for the bubbles formed by the breakage of a vapor film to diffuse, with the result that the point of time at which a characteristic point is observed lags behind that of No. 1.

[0078] On the other hand, as shown in Figure 6, in the No. 5 method which involves cooling by the natural convection of the quenching oil 1, a characteristic point was observed in 3.8 seconds after the immersion of a test piece in the quenching oil 1. In the No. 6 method which involves cooling by jet-stirring the quenching oil 1, a characteristic point was observed in 3.5 seconds after the immersion of a test piece in the quenching oil.

[0079] From the above results, it became apparent that a metal part can be rapidly cooled by breaking a vapor film without the stirring of the quenching oil 1 and stirring the quenching oil 1 after the vapor films begins to be broken.

[0080] The characteristic point of No. 1 was a temperature about 20°C higher than the characteristic points of No. 2 to No. 4 and this temperature was about 50°C higher than the characteristic points of Nos. 5 and 6. From the results, when cooling is performed under the

condition of No. 1, it could be ascertained that the breakage of a vapor film is caused by the shattering of the stability of the vapor film, and is not due to a drop of the surface temperature of a metal part.

[0081] Subsequently, metal parts were subjected to carburizing treatment and cooling thereafter was performed by the method of the present invention and by a conventional method. Dimensional changes of the metal parts before and after the heat treatment were investigated as follows.

[0082] First, ring-shaped materials made of SCM420 (outside diameter: 70 mm, inside diameter: 55 mm, axial length: 40 mm) were prepared. The ring-shaped materials were arranged in a furnace which had been brought into a reducing atmosphere by adding alcohol dropwise at 920°C, with the axial direction of the materials aligned in a vertical direction. Next, while propane gas being added into this furnace in a reducing atmosphere, carburizing treatment was performed for 60 minutes, with the carbon concentration of the atmosphere kept at 0.8%. Next, the temperature of the ring-shaped materials was lowered to 850°C in the furnace in a reducing atmosphere.

[0083] Next, the ring-shaped materials were transferred from the heating device 40 shown in Figure 1 into the cooling tank 2. This cooling tank 2 contains a quenching oil (a cooling liquid) 1 at 70°C, and the area above the quenching oil 1 is held in a nonoxidizing atmosphere. The ring-shaped materials were immersed in this quenching oil 1. And cooling was performed under the conditions of No. 10 to No. 15.

[0084] In No. 10, the oscillation device 10 was actuated, whereby the oscillating plate 11 was caused to oscillate with a frequency of 40 Hz and an amplitude of 4 mm, and the oscillations were applied to the quenching oil 1 for 60 seconds.

[0085] In No. 11, the oscillation device 10 was actuated, whereby the oscillating plate 11 was caused to oscillate with a frequency of 60 Hz and an amplitude of 2 mm, and the oscillations were applied to the quenching oil 1 for 60 seconds.

[0086] In No. 12, the oscillation device 10 was actuated, whereby the oscillating plate 11 was caused to oscillate with a frequency of 40 Hz and an amplitude of 4 mm, and

simultaneously the stirrer 20 was actuated, whereby the quenching oil 1 was jet-stirred by upward flows at a flow rate of 30 m^3/h for 60 seconds.

[0087] In No. 13, first, the oscillation device 10 was actuated, whereby the oscillating plate 11 was caused to oscillate with a frequency of 40 Hz and an amplitude of 4 mm, and the oscillations were applied to the quenching oil 1 for 2 seconds. Next, the oscillation device 10 was stopped and simultaneously the stirrer 20 was actuated, whereby the quenching oil 1 was jet-stirred by upward flows at a flow rate of 30 m^3/h for 60 seconds.

[0088] In No. 14, the stirrer 20 was actuated, whereby the quenching oil 1 was jet-stirred by upward flows at a flow rate of 30 m^3/h for 60 seconds.

[0089] In No. 15, the quenching oil 1 was allowed to undergo natural convection and a ring-shaped material was immersed in this quenching oil 1 for 5 minutes.

[0090] And for each of the ring-shaped materials after the cooling treatment, outside diameters and out-of-roundness were measured in both end portions and middle portion in the axial direction, and changes in the outside diameter and out-of-roundness before and after the heat treatment were investigated. The results are shown in Table 1.

[0091] In Table 1, the numerical values of outside diameter marked with "+" mean that the size increased after the heat treatment, and the numerical values marked with "-" mean that the size decreased after the heat treatment. Maximum differences in dimensional changes between top end, middle and bottom end are also shown in Table 1. The smaller the maximum difference in outside diameter, the smaller the deformation difference in the axial direction of a ring-shaped material after the heat treatment.

[0092] As shown in Table 1, in the methods of Nos. 10 to 13 which involve performing cooling by applying oscillations to the quenching oil 1, the maximum difference in outside diameter was small compared to the method of No. 14 which involves performing cooling by the jet-stirring of the quenching oil 1 and the method of No. 15 which involves performing cooling by the natural convection of the quenching oil 1.

[0093] Among the methods of No. 10 to No. 13, the maximum difference in outside diameter was very small in No. 13 which involves performing cooling by the jet-stirring of the quenching oil 1 after the application of oscillations to the quenching oil 1. In No. 11

which involves performing cooling by the application of oscillations having a high frequency and a small amplitude to the quenching oil 1, the effect of oscillations was small and showed that the maximum difference in outside diameter was large compared to Nos. 10, 12 and 13.

[0094] In Nos. 10 to 13, changes in out-of-roundness were small compared to No. 14 which involves performing cooling by the jet-stirring of the quenching oil 1, and out-of-roundness of the same degree as in No. 15 which involves performing cooling by the natural convection of the quenching oil 1 was obtained.

[0095] From the above results, it became apparent that by breaking a vapor film without stirring a quenching oil and by stirring the quenching oil after the vapor film begins to be broken, the nonuniformity of axial deformation of an obtained metal part can be improved.

[Table 1]

Method of quenching treatment	Change in outside diameter (μm)				Change in out-of-roundness (μm)			
	Top end	Middle	Bottom end	Differ-ence	Top end	Middle	Bottom end	Differ-ence
10	+9	+1	+34	33	37	26	41	35
11	-14	-3	+25	39	43	29	35	36
12	+6	+4	+36	32	41	33	40	38
13	+12	+8	+31	23	42	29	36	36
14	-28	-7	+32	60	53	34	45	44
15	-27	-10	+21	48	45	27	37	36

Industrial Applicability

[0096] According to the present invention, a repeatedly varying pressure is applied to a vapor film formed on the surface of a metal part and the vapor film is broken without the stirring of a cooling liquid, with the result that strong flows are not generated in the cooling liquid. Therefore, it becomes easy that the vapor film is uniformly broken. Hence, the uniformity of the cooling of the metal part is improved and the deformation or the soft spots thereof become less apt to occur. As a result of this, it becomes easy to obtain high-accuracy and high-quality metal parts.